Department of Science and Agriculture

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THE CONTROL OF SCARABEE

(Euscepes batatae, Waterh.)

IN BARBADOS.

By

R. W. E. TUCKER, M.A., B.Ed.

INTRODUCTION.

The sweet potato (*Ipomoea Batatae*, Poir.) is a valuable food crop in Barbados, and at one time, held a useful place in the exports of the Island, as well as in the local market. Loss of crop, due to damage by scarabee, has therefore necessitated an investigation into means of controlling the pest and reducing the loss.

Apart from different varieties, two types of potato are grown; namely a short period type, of which the crop ripens and is dug within three months of planting, and a long period type which may be kept in the ground for six months or more.

It is the long period crop which usually suffers most heavily from scarabee attack.

Moreover, a further division as to extent of attack can be made, according to whether the crop is grown in the drier, coastal, black soil areas, or the hillier, moister, red soil areas.

In the black soil areas, a long period crop is rarely successful, owing to scarabee attack and short period crops are often attacked; whereas, in the red soil areas, short period crops are very rarely, if ever, attacked, and long period crops are only occasionally slightly attacked, if left in the soil too long, say for eight or nine months.

The reason for this localisation of attack, in a small Island such as Barbados, is not yet fully understood.

It is possible that moisture content and texture of the soil in the hillier, red soil areas may, in the case of scarabee, be a controlling factor, and the question of increasing soil moisture content by irrigation, as a control in black soil areas, has, with other control measures, been investigated.

Euscepes batatae has no known parasite or predators, and the presence of even two or three larvae in a sweet potato tuber (sweet potato tubers are much larger than ordinary potatoes) will render the tuber unfit for consumption: animals will not eat infested tubers.

DESCRIPTION OF *EUSCEPES BATATAE*.

Adult Stage :

This is a small weevil or snout beetle (Curculionid) about 3.8 mm. long and 1.8 mm. broad. It is greyish black in colour when adult, and has a whitish fleck on the posterior portion of each elytrum, the two flecks forming a broken bar. It is thus indistinguishable in colour from the black soils in which it thrives in Barbados, which, in addition, are flecked with small granules of crushed whitish coral rock.

Young adults of a few hours old are soft and yellowish in colour; later they turn a reddish brown colour and, after a few days, become normal greyish black and hard. They do not emerge from their place of pupation in tubers or stems until fully hardened and dark in colour. They emerge by boring tunnels to the exterior, or by passing along a tunnel made by a previously emerged beetle. If very young beetles are confined with older beetles without food, the older beetles will eat the young ones.

With food, adult beetles have lived for ten and a half months, though the average life in captivity is around four months. Adults feed by eating shallow pits in the surface of tubers.

Without food or water, the beetles can live for 1½ months.

In appearance both sexes are practically identical in size and identical in colour; in size, females are slightly broader, deeper and stronger in build, but the difference is so slight that it may be masked by nutritional effects. With practice, however, sexes can be distinguished by examining the final ventral segment. In the case of females, the last ventral segment curves upwards, and in the male it is nearly flat. By getting the beetles in a suitable light, ventral surface upwards, the shadow or hollow caused by the above structural difference serves to distinguish the females from males, but practice in sex separation is needed. In addition, the females drop the final segment below the elytra more readily than males do, thus making the elytra in the females appear to project beyond and to curve downwards and over the ultimate tergites of the abdomen; this, however, is not a consistent or reliable guide, but can be combined with the foregoing characteristics. Males and females hatch in approximately equal numbers under laboratory conditions.

The adult beetles are very hardy: as stated, they can live for forty-five days in captivity without food or water. They can also remain alive for some days fully immersed in water: up to forty per cent. recover after seven days' immersion; eleven days' immersion is, however, fatal to all.

They can remain alive for some months (according to situation and condition) when buried several inches under the soil: this fact is discussed more fully below as it has a direct bearing on survival in the field, and possible spread or carry-over of infestation.

The beetles have also considerable powers of clinging, and can walk with ease up a vertical wet glass surface; but they do not seem to be able to fly.

The lack of power of flight seems to be strange, as flight wings are present beneath the elytra, but they are comparatively delicate and fragile, and do not appear to be used.

The elytra have to be forced apart or broken in order to disclose the flight wings, and the beetles do not take to flight under any form of provocation : they can be exposed to flame, or heat in other forms, or thrown repeatedly into the air, without taking to flight : they will even starve to death in an open box from which tanglefoot barriers prevent their crawling out, without escaping by flight, even though food is suspended directly above them. The only occasion on which the flight wings have been seen partially protruded from beneath the hinder portion of the elytra is when the beetles are allowed to drown in water.

This also has considerable bearing on the infestation of scarabee, for if the beetles are incapable of flight, as seems to be the case, the scope and range of infestation is considerably narrowed.

The beetles feign death readily for considerable periods, and appear to be less active by day than by night. There are no records of their migrating to or flying to lights at night.

Pupal Stage :

The length of the pupal stage varies slightly at different times of the year, during December, January, February, March and April, the average of a large series of life history records shows an average of eight days spent in the pupal stage, with nine days as the most prevalent figure in January and February: for the remaining seven months of the year, the average pupal stage is seven days.

Certain parts of the pupae change in colour as the pupal stage progresses, and, by examining these parts, the age of a pupa from the day it pupated can be determined fairly accurately. These parts are the eyes, feet and mandibles. On the first day, all parts of the pupa are of the same colour. The eyes are the first index of change, and they show, very faintly, when the pupa is one day old: they gradually get darker, until, by the fifth day, they are dark black and the mandibles appear bright red. On the sixth day the mandibles are dark red or nearly black, the joints of the feet are red, and most of the body, especially the elytra, has a reddish sheen. The adult stage, as stated, is reached from the 7th day to the 9th: during the longer period of pupation, the changes noted are lengthened out.

Larval Stage :

This appears to be very irregular and accounts for much of the divergence in life history periods, as both egg stage and pupal stage do not vary by more than a day or two respectively.

The condition of the food supply appears to be a determining factor; if the potato is fresh and newly attacked, the larval period is minimal and pupation rapid: the average larval stage in such cases being twenty days. As the food supply becomes more infested and fouled, the larval period lengthens to thirty days or more: this may be the natural reaction to a lessened and less accessible

food supply, or may be a provision for the distribution of beetles, or 'hang over' of infestation, as infested material is far too often discarded and left to rot in fields. The same applies to larvae found in potato vines in the thicker lower portions, and in the stems at leaf axils; the length of the larval period in such situations is irregular and depends on the condition of the stem or "slip"; the latter term being used for portions of the vines used for planting potato fields.

Old and apparently dried out vines, which had been dug up and discarded from a reaped field, were found, when examined three or four weeks later to contain both living larvae and pupae.

Larvae and eggs are found in slips used as planting material; the percentage of infestation of such material is given when discussing methods and rate of scarabee infestation. Pupae, as well as larvae, are found in the older woodier portions of stems.

The Egg Stage.

This stage has provided some interesting records. No eggs could, at first, be found on vines, stems or tubers taken from the field, and in captivity, the occasional globular, whitish eggs, smaller than a pin's head, which were found, were taken as normally laid eggs. Actually, they were abnormal, for the beetle conceals its eggs, and, as a result, laboratory records of egg deposition were found to be widely at variance with the obvious reproductive capacity of the beetle.

Normal eggs are laid in shallow pits made in the potato tubers, or vines, and, less frequently, a short way up the leaf stem above the axil, but never, as yet, recorded on leaves. They are then covered over with an anal secretion, which varies from dirty white to black, and does not always darken with age. The coverings are, however, inconspicuous on tubers and stems, and can easily be taken for normal field marks or flecks until they are recognised and distinguished by practice. Small cakes of soil sometimes adhere to the surface of potatoes, and the beetles will lay around and under the edges of such cakes, or around any portion of the potato where the epidermis has been scraped or damaged and a latex healed wound formed.

Occasionally an egg is laid and not covered by secretion, or is laid on top of the secretion. Eggs laid without secretion are laid thus because of unusual circumstances; thus, beetles confined in a tin or tube without food will lay naked, but viable, eggs: old and weak females will lay naked eggs, but these very frequently, are not viable, and do not hatch.

Presumably, the secretion which covers the eggs protects them from parasites and from mites and other predators such as thrips larvae, as naked eggs have frequently been found sucked empty, presumably by predaceous mites or by thrips seen near such eggs. The young larvae bore directly into the surface on which they are laid, immediately under the secretion cover.

Unmated females will lay unfertilised eggs of which a fair number (12 to 20 per cent.) are not covered by secretion. Whether covered or not, no infertile eggs have ever been found to hatch, and most of them shrivel up a few days after being laid.

Normally laid, fertile eggs, have a very high hatching rate. To judge from laboratory records (which are the only ones possible and which have been made continuously for over twelve months), the normal hatching rate should be close on 100 per cent. Laboratory records show that usually over 95 per cent. of the eggs laid hatch; and, as, in the first place, the secretal coverings have to be lifted to certify that an egg is there (very very rarely are two eggs found under one cover) and in the second place the young larvae have to be found by dissection, in the substance of the tuber, it is obvious that some mechanical damage to eggs in lifting the covers, or obliteration of young larvae in looking for them must result; the high laboratory rate of hatching would, therefore, indicate an approximation to 100 per cent. field hatch. As stated, the secretal covering most likely protects the eggs from predators, and only accidentally laid naked eggs are devoured.

The high hatching rate, taken in consideration with absence of parasitism and the reproductive capacity of the beetles, and larval survival given later, and the fact that the average time, from emergence of adults to commencement of egg laying is 15 days, and that females can lay fertile eggs over a period of four to six months, goes far towards explaining the severity of attacks when once a potato field becomes infested.

The average period from egg deposition to hatching is six to seven days.

Total Life Cycle.

From a long series of records, this can be given as:—

	Minimum.	*Maximum.*
Egg	6 days	7 days
Larva	20 „	30 „
Pupa	7 „	9 „
	33 „	46 „

The maximum cycle is known definitely to reach 46 days under laboratory conditions: under field conditions, the larval stage may possibly be further extended, as old, heavily infested potatoes, which have reached the stage of dried, mummified shells, can be found in old potato fields, and such potatoes contain living larvae and pupae. To this must be added the fact that adult beetles can live in the soil apparently without food for a considerable time, and with food, such as is invariably left in old potato fields in the shape of very small tubers or large roots, broken off and left living in the soil, an infested potato field can remain infested for a considerable period.

Alternate Host Plants :

Experimental plots were planted with sweet and bitter cassava, ginger, arrowroot, eddoes, cannas and *Ipomoea biloba* which is prevalent on the sandy seashores around the Island, but not present in cultivated areas. This sea-shore *Ipomoea*, however, grew readily in experimental plots, and, when the plots were dug up after several months of growth, there was considerable infestation in the roots and woody parts of the stems and new infestation in the younger stems; living larvae and pupae being found.

The other plants and crops mentioned were not attacked, and, as they had an equal chance with the *Ipomoea biloba* of being attacked, it can be presumed that they are not alternate host plants.

No alternate host plant other than *Ipomoea biloba* has been found. As stated, this plant is not to be found in the cultivated areas, particularly the hillier portion of the Island where scarabee seldom appears, and is not considered an economic pest; but it does appear as a fairly frequent and heavy border to the coastal black soil areas where scarabee, which apparently does not fly, is prevalent to the extent of being a pest. This may be coincidence and differential infestation may be due, as stated previously, to the higher, moisture conditions of the immune red soils, (which do not differ chemically from the black), for there is little doubt that infested planting material is taken with sufficient frequency from black soil areas to red soil areas, to cause noticeable, if sporadic, infestation in the latter areas.

As will be shown, planting material is most probably the main source of field infestation, so the question of where planting material is obtained is an important one. As stated, there is little doubt that material for planting in the red soils is occasionally obtained from black soil areas, but, as potatoes can be kept in the ground longer in the red soil areas it is probable that most material is obtained locally in red soil areas, and that much planting material for coastal black soil areas is also obtained from red soil areas.

Methods and Power of Survival or of Transport:

Survival: It has been stated that the larval period can be extended under unfavourable conditions, and that the adult is very hardy though sluggish, and is able to exist for considerable periods without food or water, and to be able to withstand a considerable period of immersion in water. There remains the power of keeping alive when buried voluntarily or involuntarily in the soil of fields.

Examinations were first made by examining, *in situ*, the soil of a field which was known to have had infested potatoes in it. As the beetle has been described as being small, coloured and marked like the soil, and ready to feign death or remain motionless, it is obviously not easy to find the beetles by direct search: nevertheless, five living beetles were found under stones or a few inches under the surface of the soil by this method several weeks after the crop had been removed.

Another method then tried was to take samples of soil at random from the field, put it into bags, and examine it in the laboratory. It was not possible to examine a large number of samples. Altogether seventy samples were examined in this manner (it was found by experiment that all live beetles placed in a bag of soil and well mixed, could be recovered through floating by stirring the soil in a large receptacle of water). Eight live and seven dead beetles were recovered in this way.

Considering the limited samples which could be examined, and the fact that living beetles were obtained three months after the crop had been removed and other crops planted, it is reasonable to consider that, under favourable conditions, *Euscepes batatae* can remain alive in the soil for a period of some months.

A laboratory experiment in which the young beetles, of one sex only, were placed in the soil in each of eight Kilner jars was also tried. Four jars had males only and four females only: of these, an equal proportion had food and water, food and no water, and no food and no water. Only one experiment gave results worth recording, and that was the jar containing males with food and moisture, and, in this case, nine out of ten beetles remained alive for six months: by the end of the seventh month all were dead; for some reason, beetles in the other jars died rapidly.

Though this one jar is an indication of longevity on the part of the beetles when buried five or six inches under the soil with moisture and food, these experiments were not carried further because the field experiments originally tried were too arduous, and the laboratory experiments would have to be elaborated to the extent of taking up too much time and space to get accurate results.

The most that can be said is that survival of adults in the soil, quite apart from material left through bad cleaning of the fields, is extremely probable for a period of some months after removal of the crop.

In the case of badly cleaned fields survival for several months is certain.

Transport:

As available evidence points to lack of powers of flight on the part of *Euscepes batatae*, transport must be by mechanical means.

Sweet potatoes are propagated in Barbados entirely by 'slips' or cuttings, which are transported from place to place as fields are required for planting to potatoes.

These slips definitely carry living larvae, and obviously an infested field will have cuttings infested in proportion to infestation of that field, and a non-infested field will have clean cuttings.

Examinations of cuttings were made from various sources, infested and non-infested, over a period of seventeen consecutive months, and for three months apart from the above consecutive examinations. Altogther 27,025 cuttings were examined, and, taking infested sources only, a maximum of 21 per cent. and a minimum of 0.21 per cent. cuttings were found to be infested with scarabee. The average infestation from infested sources was 4.11%: the significance of this is discussed later. It cannot be said that any period of the year showed a higher percentage of cuttings infested than any other period: the age and degree of infestation of the field are the determining factors in the amount of infestation present and transported in cuttings.

Adults, pupae, larvae and eggs can be transported in refuse such as potato vines, which are used to cover the potatoes when loaded into carts, and which are also used and sold as food for stock.

Infested potatoes, which cannot be sold as food, even for stock, are usually allowed to rot in the ground and on the surface of the ground: those on the surface containing long cycle larvae may be transported elsewhere, though there is no obvious reason for anyone doing so, except to destroy them.

There is also a possibility of adult beetles clinging to clothing, particularly the skirts of the female labourers, and so being taken from infested peasant plots to plantation plots and *vice versa*.

The principal and most definite form of transport of the pest is undoubtedly in 'slips' or cuttings, for planting purposes.

Control experiments have, therefore, been concentrated on destroying infestation in slips, or preventing infestation after planting: attention was also given to soil fumigants and poisons, to prevent adult beetles in the soil from reaching the tubers. Irrigation as a means of control was also investigated.

Rate of Establishment from known Sources of Infestation.

The only definite known source of infestation is by cuttings or slips used as planting material; as pointed out, infestation due to migration by flight does not seem likely, and spread, due to transportation of infested vines or tubers, though possible does not seem to be probable. Infestation due to planting potatoes in a field which has had potatoes growing in it some months previously, even though the previous crop was not noticeably affected, is, however, a certainty.

Presuming, however, that plantings of sweet potatoes are made in fields which have not had potatoes in them for over a year, and which are not contiguous to a field or fields which have recently had a crop of potatoes, laboratory and field records combined show that it is possible for fields to be infested from planting material, and for the infestation rapidly to reach damaging proportions.

Field examinations have shown that, of 18,705 slips examined from slight to badly infested fields, an average of 4.11 per cent. slips are infested, the highest infestation found being 21.0 per cent. and the lowest 0.21 per cent. Many fields examined give entirely negative results, i.e. no infested slips at all.

Fields planted in clean soil with non-infested slips stand an excellent chance of never being infested at all.

Fields planted with an average of 4.11 per cent. infested slips will be infested as follows:

On an average, 4,500 slips or cuttings are planted per acre: therefore, if 4.11 per cent. are infested, the potential beetle population of the field is 185.0 beetles. Of these, a long series of laboratory records show that approximately 50 per cent.* will be females. There are thus 92.5 females potentially due to hatch out per acre: actually the number will be less, as all eggs or larvae in or on the slips do not reach maturity; though, as stated, mortality rate in the life cycle is low.

Presuming however that only 50 females per acre, with corresponding males, reach maturity (i.e. just over 50 per cent. of average potential infestation), Laboratory experiments show that virgin pairs mated, and timed for the female to commence laying on the first of a month, gave, during the lifetime of the female, an average of 106 eggs per female per month.

* Out of 9,067 *Euscepes batatae* beetles examined 50.4 per cent. were females.

This is shown by the following records:—

Egg deposition starting on	Average for 3 females.
January 1st.	434.0 eggs per female.
February „	282.3 „ „ „
March „	533.0 „ „ „
April „	470.7 „ „ „
May „	437.3 „ „ „
June „	314.0 „ „ „
July „	504.7 „ „ „
August „	425.3 „ „ „
September „	303.0 „ „ „
October „	355.3 „ „ „
November „	596.7 „ „ „
December „	437.3 „ „ „

During an average life of four months per female, this gives an average total of 424.6 eggs per female, i.e. 106 eggs per female per month.

The period of four months life per female is arrived at as follows. For twelve consecutive months, three newly mated male and female pairs were kept under observation. The records for these twelve sets of three pairs is as follows :

Started	in	January	average	life	4.7 months
„		February	„	„	3.0 „
„		March	„	„	4.3 „
„		April	„	„	4.3 „
„		May	„	„	3.7 „
„		June	„	„	3.3 „
„		July	„	„	4.0 „
„		August	„	„	5.7 „
„		September	„	„	3.0 „
„		October	„	„	4.3 „
„		November	„	„	5.0 „
„		December	„	„	4.0 „

The general average of which is just over four months.

In these figures, two points stand out, namely, that some females of a pair laid eggs over a period of seven months, and that the highest number of eggs laid by the females of any pair during one month was 669.

On the other hand the females of some pairs did not live more than two or three months: none ever lived less than two months. Naturally, in laboratory records of this nature the containers used for the beetles and their food and progeny, become very numerous in order to keep records of the number of eggs laid per pair per day, the position in which the eggs were laid on the food supplied, the number of eggs hatching, and the resultant number of adults emerging. It is, therefore, not surprising that sometimes an occasional beetle escaped, or that some were killed accidentally, or had their natural lives curtailed. Such unavoidable occasional mischances naturally cause a fluctuation in the total number of eggs recorded per pair of beetles: also, owing to each egg being hidden as previously described, it is quite possible that all eggs were not found on all occasions. The figures obtained also show that there is no definite seasonal abundance or scarcity of eggs, but that the beetles appear to lay at the same rate throughout the year.

It can readily be seen, however, that with a possible 50 female beetles per acre, due to using infested slips for propagation, and a possible average of over 106 eggs per female per month, and no natural controls, it does not take long before a field, which is planted with a sufficient number of infested slips to provide adequate males and females for starting the first generation, becomes badly infested.

As stated above, the general average of eggs per female per month is 106: this can be compared with the following independent records.

Parallel records were kept of pairs of newly mated females placed in jars with a whole potato and allowed to breed. Each month, for a period of twelve months a mated pair was placed in each of five jars and allowed to breed. As beetles emerged from the potato, they were removed so as to prevent further breeding; also, at the end of the normal cycle, namely between 33 and 40 days, the potatoes were removed and broken into pieces and all adults removed and counted. Some allowance had to be made for pupae and advanced stage larvae, and also for the fact that though beetles were removed as stated to prevent breeding, it is possible that all beetles do not emerge from the potatoes in which they have pupated, but burrow inside, mate, and start another generation without coming out at all. As far as possible, allowance was made for this fact, but doubtless, in some cases, a proportion of second generation was recorded as progeny of the original pair.

This possibility is recognised, but is not considered seriously to detract from the figures given below, which are placed on record as indicating the breeding potentialities of *Euscepes batatae* and not as accurate progeny records. The figure for each month is the average of progeny counts made from five mated females.

January	92.8	July	98.6
February	78.0	August	64.8
March	64.8	September	79.2
April	78.6	October	117.8
May	190.0	November	176.0
June	110.6	December	102.0

The mean of these monthly records is 104 progeny from each mated female.

The comparison between this figure and that of the mean figure of 106 eggs per female per month over a similar twelve month series of counts of eggs deposited, shows sufficient agreement to make it highly probable that a figure around 106 eggs per month during the lifetime of a female scarabee is correct, and that mortality from egg stage to adult is, as has already been stated, low.

Two other points of interest arise from this series of laboratory records. One is, that beetles bred in jars as described sometimes lay a number of eggs in a cluster around an opening bored to the exterior of the potato, and cover these eggs with one large mass of secretion: this appears to be a contradiction of the statement that eggs are laid singly and *very* rarely, in pairs, covered by secretion . As this phenomenon has never yet been found in field planting material examined, nor in other laboratory experiments, it is concluded that the above occurrence is the result of the condition of the experiment in question.

The other point is that the progeny figures above are at their highest in May, June and July, and in October, November and December; the principal months of planting potato slips being June and November of each year, varying with local or general rainfall.

This may be merely coincidence, for the egg laying records show no marked variations: each mated female of each monthly series starting off with a high daily average for each initial month, and falling off in reproductive powers month by month until cessation due to death.

As the time of potato planting is governed in the main by rainfall, control of scarabee by changing planting dates does not hold any promise.

From laboratory and field data recorded so far, control must come through field sanitation, from avoidance of planting anywhere near a field which has had potatoes in it at any recent period, and, above all, from planting cuttings free from scarabee. To this can be added control by spraying potato vines with lead arsenate, and beneficial results of irrigation as is indicated in the following details of controlled experiments.

Control of Scarabee:

Field sanitation should need no emphasis: it is common sense good farming: nevertheless fields of infested potatoes are left to rot in the ground, and infested tubers are left lying *in situ* in some cases. Infestation in such areas is therefore likely to continue.

Assuming however a proper clean-up of fields, and a wish to plant scarabee-free cuttings, the latter point is not always attainable. In the first place, it takes some practice to pick out cuttings that have young scarabee larvae in them, or that have scarabee eggs laid on them, and in the second place, the percentage of infested cuttings is usually low, because it is very rarely that cuttings for propagation purposes are taken from a field known to be heavily infested. Yet, as shown, a small percentage infestation of the thousands of slips used per acre can cause a slight to moderately heavy infestation in a three months' crop, and a medium to very heavy infestation in a long period crop.

Experiments were therefore planned to test the possibilities of:—

I. Destroying eggs and young larvae and pupae in planting material by dipping the cuttings in insecticides prior to planting.

II. Incorporating fumigants or poisons in the soil prior to planting so as to prevent infestation from reaching the tubers when they formed.

III. Spraying and dusting the vines with insecticide during growth.

IV. Testing irrigation, and flat, instead of hill, planting, as control measures.

First of all, the method of planting sweet potatoes in Barbados must be explained. Potatoes are planted as catch crops or provision crops in fields which have had canes planted in them, and which will revert to cane planting: such fields, therefore, are prepared with cane holes according to the usual system in Barbados. The number of cane holes may range from 1,200 per acre in some areas to 1,742 per acre in others: a fair average being 1,500 holes per acre. Between the cane holes are the 'banks,' and sweet potato slips are planted in the banks in raised mounds of soil, or hills, three hills to a cane hole.

There is thus an average of 4.500 hills per acre, and, as the usual planting rate is one slip per hill, 4,500 cuttings are required per acre.

The dipping of slips in an insecticide has therefore to give a high kill of scarabee, if present, without interference with the rooting of the slips, as well as being cheap to stand any chance of success.

The use of soil fumigants or poisons is limited to incorporation of the fumigant or poison in the hills when they are being prepared, and is somewhat laborious and relatively expensive.

Both irrigation and flat planting are designed to minimise the amount of cracking of the soil around the growing tubers, and so limiting access of the beetles to the tubers.

Preliminary experiments were carried out with plots planted in hills, flat, controls and hills treated with lead arsenate 1 oz to five square yards, and with naphthalene at the rate of one ounce per square yard in the soil. In other plots, vines were sprayed with lead arsenate. Other plots were planted with slips dipped in Ialine Tar Wash, 7½ per cent. strength, and 10 per cent. strength: Niagara Emulso 2 per cent. and Mulsulphol 4 per cent.: immersion of slips was for two minutes save in case of Niagara Emulso, when immersion was for five minutes.

These experiments indicated that flat planting diminished yields very considerably without appreciably diminishing infestation. They also showed that soil treatments were laborious and expensive; that dipping of slips caused heavy failures in growth, and failure to form tubers without preventing infestation. Lead arsenate spray, however, minimised, though it did not prevent, infestation, and appeared to stimulate both yield and growth of potatoes.

In 1936, therefore, a full series of experiments were laid out in randomised blocks, so as to make a definite comparison of selected treatments, some as above and some new.

The lay-out of the experiments was as follows:

I.	II	III.	IV.	V.
J	E	D	I	C
H	G	I	K	F
C	K	K	C	A
A	D	J	J	E
G	B	A	F	D
E	H	C	A	K
B	J	F	E	I
K	F	N	D	H
F	I	B	H	B
I	A	E	G	J
D	C	G	B	G

The experiment consisted of five blocks.

In each block were eleven plots.

The plots were randomised in each block.

Each plot consisted of 48 potato hills: i.e. 16 cane holes or approximately 0.0083 of an acre (1,920 cane holes per acre).

There are thus five replicates of each treatment. Only one potato slip was planted per hill.

The treatments are as detailed below:—

Controls: A. Five plots each planted with selected *non-infested* slips.
B. Five plots each planted with 100 per cent. infested slips.*

* An infested slip is one that has evidence of larval infestation, or on which one or more *Euscepes* eggs are found: this does not mean that in all cases the slip carried living larvae which would reach adult stage, or that the egg or eggs succeeded in infesting the slip.

	C. Five plots treated with lead arsenate at four ounces per hill.
Soil Treatment	D. Five plots treated with Ialine Soil fumigant at three ounces per hill.
	E. Five plots treated with two per cent. Pyridine solution: two applications.
	F. Five plots sprayed with lead arsenate, 2 oz. to 4 gallons of water and a half cupful of molasses.
Spraying and Dusting Vines.	G. Five plots sprayed with colloidal lead arsenate, 2 pints to 100 gallons.
	H. Five plots dusted with Dutox.
	I. Five plots with slips dipped for one minute in 5 per cent. Carbo Craven.
Dipping Slips:	J. Five plots planted with slips dipped for one minute in 5 per cent. Ialine Solution.
	K. Five plots planted with slips dipped for one minute in 3 per cent. Mulsulphol solution.

All plots were planted out on July 21st, 1936. Soil treatments C and D were carried out on July 23rd. Treatment E with Pyridine 2 per cent. solution at the rate of 4 gallons per 48 hills, was given on August 26th, by which time the slips had rooted and started growth; and again on October 21st, when tubers were well formed. The odour of the original treatment with Pyridine was perceptible to nearly the end of September in the soil treated, despite an intervening fall of two inches of rain. The odour of the Ialine soil fumigant was also perceptible two months after treatment.

Treatments F, G and H were carried out on August 26th, September 17th, and October 21st, for all plots. The "Dutox" was applied by a rotary duster, and, in the case of vines fully grown and covering all the soil in the plots, seven pounds of dust were required for the entire five plots of 48 hills each. With only a moderate wind blowing the dust drifted three to four yards or more over other plots, though the duster nozzle was held as close as possible to the soil; in a high wind, dusting of individual plots was difficult and wasteful.

The results of the various treatments on the appearance and vegetative growth of the plots was as follows: the effect on yield of potatoes is tabulated later.

Mortality of slips in control plots A, planted with selected non-infested slips, was 0.0 per cent: mortality in control plots B planted with infested slips was 1.2 per cent. General growth not quite so good as in selected free cuttings plots.

Mortality of slips in plots C treated with lead arsenate in the soil was slightly less than the above figure, but general growth at first was not quite so good, though not differing appreciably later on.

Mortality in Ialine soil fumigant plots D was 4.5 per cent. and general growth poor at first.

Pyridine plots E were not treated till plants were well established: hence mortality of slips and growth conditions are, from records, the same as for B control plots.

Spray treatments F, G and H were also not made until vines were well established: slip mortality in F and H plots was, in both instances, 2 per cent. and in G negligible; in all plots growth was fair to moderate.

The slip dipping treatments I, J and K, were, however, failures from the start, because the rate of mortality in the slips was too high for any plantation practice, and the growth of those that did not die was uniformly very poor. Mortality records of slips planted were:—I—33.3 per cent., J—44 per cent., and K—17.5 per cent.

The lead arsenate spray treatments were in no way detrimental to the growth of the vines. Records were kept of the covering power and durability of the ordinary lead arsenate—plus molasses, and of the colloidal lead arsenate sprays. The colloidal lead arsenate spray had an advantage in evenness and fineness of covering the foliage, and a slight advantage in durability; nevertheless, the final plot yields and scarabee infestation counts do not show sufficient difference to offset the greatly increased cost of using colloidal lead arsenate.

Dutox dust was not only not so successful as a control measure as lead arsenate spray, but caused a definite yellowing and dropping of many leaves of the vines in the plots treated.

The final yields of the different treatments are tabulated below, the mean of all five plots of each treatment being taken.

TABLE I.

Variety.	Treatment	Mean of Yield over 5 plots.		Scarabee Infestation Mean of 5 plots.		Nett Yield per Treatment. Mean of 5 plots
		Number of Potatoes.	Weight in lb.	Number of Potatoes.	Weight in lb.	
V. 52	A. Control. Clean	96.2	92.4	29.0	24.6	67.8
V. 52	B. Control. Infested	79.6	69.0	31.2	35.4	33.6
V. 52	C. Lead arsenate in soil	43.8	56.4	0.6	1.8	54.6
V. 52	D. Ialine fumigant in soil	35.2	35.4	10.2	12.2	23.2
V. 52	E. 2% Pyridine in soil	86.0	80.6	24.8	27.1	53.5
V. 52	F. Lead arsenate spray	110.4	121.5	4.2	5.7	115.8
V. 52	G. Colloidal lead arsenate spray ...	101.2	111.9	4.0	6.1	105.8
V. 52	H. Dutox dust	86.8	85.1	9.8	9.6	75.5
V. 52	I. Slips dipped	56.2	66.0	7.6	11.8	54.2
V. 52	J. „ „	44.8	48.1	11.0	13.1	35.0
V. 52	K. „ „	62.6	74.6	16.4	23.0	51.6

Scarabee infestation is obviously reduced in the case of lead arsenate treatment in the soil, and, in the case of ordinary and colloidal lead arsenate spraying of vines.

Final yields per plot, however, show that the nett average yield of 54.6 lb. per plot for lead arsenate soil treatment does not compare with the nett average yields of 115.8 and 105.8 lb. per plot for lead arsenate spraying of vines. Further the cost of lead arsenate soil treatment is prohibitive.

All treatments show a decrease in scarabee infestation over the control plots planted with infested slips, though the treated plots were planted with infested slips from the same source.

Lead arsenate sprays give definitely outstanding results, and, although Dutox dust, which is a similar treatment, though dry instead of wet, comes next, the only treatment which is economical as well as practical for ordinary plantation routine, is the spraying of vines with ordinary lead arsenate, plus molasses as sticker.

It should be noted here that these randomised, adequately replicated experiments, confirm the previous and preliminary experiments which were mentioned on page 144.

Of all treatments, therefore, lead arsenate spraying stands out conspicuously as practicable, successful and economic.

The cost of lead arsenate spraying (treatment F) works out as follows.

Amount of mixed spray used was 4 gallons per plot, a very thorough spraying being given. A plot consisted of 16 cane holes (48 hills) and there are 1,920 holes per acre according to the lay-out of this experiment;* thus 7.54 lb. lead arsenate are required per acre of 1,920 cane holes for spraying. The cost of lead arsenate in Barbados, allowing for freight and other charges, should not exceed sixteen cents per pound on the plantation: thus, one spraying, as above, costs $1.20 or 5/- per acre, plus water, labour and supervision. Supervision is definitely necessary, but, as most planting operations in Barbados are supervised, this should not be counted as an operation charge.

Thus, for three sprayings, as in the experiment conducted, the cost is $3.60 or 15 shillings per acre, to which must be added field labour and water transport. Presumably a total of $4.80 or £1. 0. 0. per acre is adequate.

The relation of this control measure cost to the value of the crop can only be approximated, as the value per acre of a crop of sweet potatoes varies somewhat.

A field of sweet potatoes is generally sold to local buyers who, after sampling a few 'hills' to determine general weight and saleability (absence of scarabee) of potatoes, offer so much per hole (of three hills) for the field

* Normal plantation lay-out does not give such a high figure, and would average around 1,500 holes per acre: hence the amount of spray per acre would be less and cost per acre would be less.

or portion of the field. They then dig up the potatoes themselves and transport them in donkey carts, with the potatoes covered over with potato vines, and sell them to itinerant vendors or hucksters.

A field, therefore, may fetch as much as ten or twelve cents (5d. or 6d.) per hole of three hills, or as low as four cents (2d.) per hole; or, if scarabee is very prevalent, it may not be bought at all, and the potatoes then rot in the ground, with effects which can be imagined from the previous text. The vines of course would be cut off for stock fodder.

Assuming, however, that a general average of holes per acre is 1,500, and that a general average price is five cents per hole, an acre of 1,500 holes would fetch seventy-five dollars: roughly £15. 12. 6.

Obviously a control of expenditure of $4.80 or £1. 0. 0. per acre is a very paying proposition, particularly as the control resulted in an increase of over seventy per cent. in the saleable weight of potatoes over the yield given by the control plots planted with clean slips.

It must be remembered that this increase relates to the average yields of the five plots each of treatments A, F, and G, the randomised positions of which can be seen from the diagrams on page 145.

Plantation yields would not, in the writer's opinion, show anything like a seventy per cent. increase in yield due to treatment because (a) the yields of the control plots A are doubtless lower than they should be, because the high figure of scarabee infestation in these plots points to the fact that scarabee found their way into these relatively small plots by plain crawling in from adjacent infested plots; and (b) the application of lead arsenate sprays was made by workers accustomed to spraying and supervised continuously by people who knew how sprays should be applied. Apart from the fact that these advantages would, it must be admitted, be lacking at first on most plantations, the standard of spraying given to small plots might not be maintained over fields of some acres in extent.

Both these factors would make the apparent advantages of treatments F and G greater than they should be over treatment A, though planters do not, or cannot as a rule, plant 100 per cent. selected free slips as used in plots A, which may offset (a) above.

Nevertheless, a control over scarabee, leading, as it should, to a gradual reduction in its prevalence, and discounting the 70 per cent. plot increase in yield given above to a 30 per cent. or 40 per cent. plantation increase in reapable crop, should make scarabee control definitely a practicable proposition.

Further, the margin of increased yield warrants the use of field pumps mounted on a one wheel chassis, for purposes of spraying, as the use of hand pumps of the "Solo" continuous action type, as used in the above experiments, would be inadequate and too hard on labour unless used at the rate of about one machine per acre sprayed. The use of one wheeled field pumps has been tried, and the cost of an adequate apparatus of this type landed in Barbados should

be around £15.* Spraying machines, if properly cared for, should last for years, and the annual capital charge per machine would be well covered by increase in crop; in less than three years, in fact, machines should be paid for by increased returns.

It is also important to recognise that the lead arsenate and molasses (sticker) sprays advocated for scarabee control, would diminish, if not control, the attacks of several potato defoliators, which, at present, are allowed to reduce a considerable acreage of sweet potato vines to bare stems every year. These defoliator attacks are rarely controlled because, as the vines usually put out fresh leaves and look normal a few weeks after the attack—if adequate rains fall—it is not considered by planters that any serious damage is done.

This '*laissez faire*' policy is not to be commended, for, apart from loss of weight in the potato crop which is bound to result, some potato defoliators (*Xylomyges eridania* in particular) also defoliate cotton and have been known to migrate to cotton fields to do so.

There is therefore much to recommend the spraying of sweet potato against scarabee, and the use of adequate spraying apparatus, as a means both of scarabee and general pest control.

The remaining field of investigation is that of irrigation *versus* non-irrigation as a control over scarabee and of varieties of potatoes which are less prone to attack by scarabee.

Evidence is being gathered on the subject of varietal susceptibility or resistance, but has not yet reached a stage for practical recommendation, and may well be left as a supplementary control measure to come at a later date, should varieties be found which do not lose in edibility whilst retaining cropping powers and acquiring scarabee resistance.

The subject of irrigation as a control is also somewhat academic so far as Barbados is concerned; nevertheless, to obtain all data bearing on scarabee control or regional limitation, a combined irrigation, lead arsenate spraying and flat *versus* hill planting was laid down in 1937.

Randomised plot irrigation was not practicable, so two blocks of randomised flat and hill planting, sprayed and unsprayed, treatments were laid down, the blocks being identical in lay-out, and then one block was irrigated at intervals, and the other was not. This experiment was carried out on ground from which potatoes infested with scarabee had been removed two weeks previously.

The results definitely confirmed that spraying with lead arsenate increases the yield of saleable potatoes when scarabee is present : that hill planting is superior to flat planting in yield, and indicates that irrigation does reduce percentage scarabee infestation, and, naturally, it definitely increases the yield.

The experiment also indicates the extreme inadvisability of planting sweet potatoes in soil which has recently had infested sweet potatoes growing in it, inasmuch as the two blocks of potatoes in question became so badly infested during the six months of their growth that it is surprising that any differences due to treatments were discernible.

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* See note on spraying at end of paper.

There were four treatments in the experiment, namely flat planting and flat planting sprayed with lead arsenate; hill planting and hill planting sprayed with lead arsenate. The flat planting and hill planting served as controls and also as comparisons between the respective types of planting.

There were ten replicates of each treatment in each of the irrigated and non-irrigated blocks, making 40 plots, each of 48 hills, in each block. The randomisation was the same for each block, the blocks being separated by three cane holes to avoid irrigation effect spreading to the non-irrigated block.

In the diagram below, hill planting and flat are represented by H, and F, and hill and flat planting sprayed by H.S. and F.S.

F_1	HS_1	F_2	H_1	HS_2
H_2	FS_1	FS_2	F_3	H_3
HS_3	HS_4	H_4	FS_3	F_4
H_5	F_5	FS_4	HS_5	H_6
F_6	H_7	F_7	H_8	HS_6
FS_5	F_8	HS_7	FS_6	HS_6
H_9	FS_9	FS_8	HS_9	F_9
HS_{10}	FS_9	H_{10}	F_{10}	FS_{10}

F_1	HS_1	F_2	H_1	HS_2
H_2	FS_1	FS_2	F_3	H_3
HS_3	HS_4	H_4	FS_3	F_4
H_5	F_5	FS_4	HS_5	H_6
F_6	H_7	F_7	H_8	HS_6
FS_5	F_8	HS_7	FS_6	HS_6
H_9	FS_9	FS_8	HS_9	F_9
HS_{10}	FS_9	H_{10}	F_{10}	FS_{10}

The result of irrigation was as follows:—

Total yield in the irrigated block of 40 plots was 1,173 lb of potatoes, of which 70.16 per cent. were infested, leaving a saleable amount of 350 lb. The total yield in the non-irrigated block was 465.5 lb. of which 85.28 per cent. were infested, leaving a saleable amount of 68.5 lb. Irrigation therefore increased the total yield from 465.5 lb. to 1,173 lb., and decreased infestation from 85.28 per cent. to 70.16 per cent.

Despite the poor yields, due to heavy infestation by scarabee, spraying the vines three times with lead arsenate again gave definite proof that scarbee infestation was reduced, and yield of potatoes increased.

Thus, the sprayed plots produced a total of 868.25 lb. of which 65 per cent. were infested, and the non-sprayed plots produced a total of 770.25 lb. of which 85 per cent. were infested. The saleable yield for the twenty randomised plots which were sprayed was 307.75 lb. and the saleable yield from the same number of unsprayed plots was 115.75 lb.

Strangely enough, the flat planted sprayed plots outyielded the hill planted sprayed plots in both irrigated and non-irrigated blocks, whereas the unsprayed hill planted plots outyielded the unsprayed flat planted plots.

The detailed results of this experiment are not given as the high general infestation due to replanting in scarabee infested ground overlays all figures. Nevertheless, even under such abnormal conditions, it is quite evident that spraying with lead arsenate and molasses as sticker, reduces infestation and increases the yield of saleable potatoes, and, as this is the third time that this fact has definitely emerged from one trial and two adequately randomised plot experiments, it is reasonable to conclude that it is a successful control measure.* Further, the increases in yield of saleable potatoes, due to control of scarabee, is so high that, not only is no statistical analysis of other yields due to different treatments necessary, but a heavy discount of yield can be allowed for when converting plot treatment into estate practice, and still make the treatment effective.

Finally, allowing plantation treatment to give less than half the increased yield obtained in plot experiments, an increase of one third in weight of saleable potatoes is reasonable. Allowing then a fairly low average price of five cents per hole, and 1,500 holes per acre, in selling the potatoes, the value of the crop per acre definitely justifies the control measures advocated, and the low increase allowed for soon covers the purchase price of the spraying apparatus advocated.

It must however be remembered that increased yield is only claimed where scarabee infestation is present and is controlled. It is not claimed that spraying a non-infested field would increase the yield, though as a preventive measure and *as a control over defoliators*, it is considered to be justifiable and economic as a routine plantation measure.

In conclusion, it must be emphasised that infestation by scarabee *cannot be seen*, does not affect the crop economically until the sweet potato tubers are formed, and is rarely discovered until the crop is ready to be dug. Once tubers have formed, and scarabee have reached them there is, to our present knowledge, no possible economic control. It follows, therefore, that control over *Euscepes batatae* is essentially preventative, and growers must be prepared to spend £1 0. 0., or approximately five dollars per acre, on a crop which may fetch from £12. 0. 0. to £22. 0. 0. per acre (according to demand or to presence or absence of scarabee) without knowing whether scarabee is present at the time or not.

* See further results at end of this paper.

Further it must be made clear that the above cash return per acre is practically nett. The land has to be 'prepared' in any case, the cost of planting sweet potatoes is low, and the cost of reaping is nil, as it is not done by the plantation, but is done by the people who buy the crop in the field as a whole.

Finally it is desired to make acknowledgment here of the extensive and often arduous work in the field and in the laboratory on life history work which was carried out by Mr. R. Peterkin of this Department.

SUMMARY.

1. The Curculionid beetle *Euscepes batatae*, Waterh, is known as the scarabee, and causes, under some conditions, considerable loss to the sweet potato crop in the low lying coastal black soil areas of Barbados. The sweet potato crop is a valuable food crop and at one time was the basis of a small export trade.

2. The life history of *E. batatae* is given in detail, and attention drawn to the protected hidden singly laid eggs, low life cycle mortality, high reproductive capacity and hardiness of the adult beetles. Only one alternate host plant (restricted to the sea shore) is known in Barbados and no natural enemies are known.

3. Methods of field infestation are examined and sources and rapidity of infestation are given.

4. Three years of control experiments showed in all cases that three consecutive sprayings of the potato vines with lead arsenate plus a sticker reduced infestation and increased yields to an outstanding extent. Details of randomised plot experiments are given; soil treatments proved relatively ineffective and definitely uneconomic.

5. The cost of the control measure per acre is worked out and is shown to be definitely economic, taking a low average price per acre of crop as a standard.

6. The control measure must be prophylactic, as field infestation by scarabee cannot be seen by ordinary inspection and could, in most cases, only be determined when potato tubers have formed. When these are infested no control measure is effective or economic.

FURTHER RESULTS ON SCARABEE CONTROL AND SPRAY EQUIPMENT.

Since the foregoing account went to press, two other field experiments on control of Scarabee by lead arsenate spraying have been concluded. In each case, the sprayed area was half an acre in extent; both experiments gave positive results. Also, in each case, the scarabee control had to be carried out in an area of mixed varieties of potatoes, and not on a homogeneous planting of one variety as in the experiments recorded in the foregoing paper. Experiments carried out on planting of one variety only are certainly preferable from the point of view of demonstrating insect control on a statistical basis.

In the first experiment now to be recorded, the varieties were in the form of blocks of randomised plots of each variety; there were twelve varieties.

In the second experiment, the field used had a heterogeneous assortment of varieties with no planned planting.

The first experiment was handicapped from the start by a delayed application of the first spraying, so that only two sprays instead of three were applied. As a possible offset to this, a heavier application of lead arsenate was made per acre, due to using a mounted barrel pump with a spray gun which gave too rapid an application of spray.

The second experiment was in the form of eighteen plots on the A.B.B.A. plan. The A plots were sprayed, and the B plots left unsprayed.

In this experiment, the spray was applied by means of a Four Oaks "Handy Pattern" tank mounted on a chasis with one small wheel. This is the type of machine suggested on p.150; the smallness of the wheel was, however, a disadvantage in both potato and cotton fields, as both crops are planted on the cane banks and the machine has to travel over a continuous series of cane holes; the wheel also clogged rapidly if the soil was wet. The machine, however, delivered the spray in an economical fashion and four sprayings were necessary to apply the required amount of lead arsenate per acre. Both experiments were handicapped by heavy showers during spraying operations; this meant that foliage on which the spray had not dried was washed nearly clean, and had to be allowed to dry, and then such plots or portions of plots had to be sprayed again. Sometimes the showers were too slight to stop operations, but merely diluted the spray during application. These plots were not sprayed again.

Finally, the weather as a whole during the main growing period of the potatoes was wet which is conducive to, and resulted in, a low general infestation of scarabee.

The above combination of circumstances handicapped these experiments from the point of view of showing mathematically significant results in reduction of scarabee infestation.

Both experiments showed a reduction in the amount of scarabee infestation, both as regards the number of potatoes infested, and weight of potatoes rendered unsaleable.

In the first or randomised varietal plot experiment, the unsprayed areas averaged 3.5% by weight of tubers infested, and the sprayed areas averaged 2.2%. This difference is not significant as the probability of the reduction in infestation being due to treatment is only 2.5 to 1. The experiment is quoted because though, as stated, the experimental conditions were adverse, and the results not significant, nevertheless, as in every test made over a series of years, the amount of scarabee was reduced by the treatment.

In the second experiment, the unsprayed B plots averaged 1.2% by weight of tubers infested, and the sprayed A plots averaged 0.5%. The difference between means of weights of infested tubers in sprayed and non-sprayed areas is significant at the usual 19 to 1 probability.

Thus in spite of low average infestation, and of handicaps which are not likely to occur all at the same time in normal plantation fields of potatoes, these two additional experiments confirm the fact that spraying with lead arsenate at the rate of 7.5 lbs. of arsenate per acre at each of three sprayings effects a control over scarabee.

The extent of control will depend on the efficiency and intelligent application of routine sprayings.

The cost will also vary with the efficiency of the spraying and with the type of machine used. With workers trained to spraying operations, and with the cost of lead arsenate reduced by wholesale or co-operative buying, the figure of $5.00 per acre for three sprayings might be reduced.

Further, as field spraying apparatus is not stocked or used commercially in Barbados, trials have to be made with machines specially imported for the purpose, and the recommendation of one-wheeled field pumps has to be qualified by the fact that such pumps can only conveniently be used in fairly level dry fields.

The type of sprayers most suitable to local conditions, fields and crops, together with cost of operation and maintenance is being investigated and it is hoped at a later date to make definite recommendations concerning machines for the spraying of both sweet potato and cotton crops; the question of spraying will also be compared in cost and efficiency, with the present method of dusting with Paris Green and lime.

LARVAL DISPERSION

OF

DIATRAEA SACCHARALIS.

BY

R. W. E. TUCKER, M.A., B.Ed.

The fact of lepidopteral larval dispersion is an established one. Young lepidopterous larvae of various kinds have been proved to be wind borne, or carried on air currents, and have been collected at various air levels by means of tanglefoot sheets on land, and by special collecting devices on aeroplanes. Larval dispersion, especially of economic pests does not, however, appear to be assessed at present at its true value, and actual measurements of larval dispersion and survival are rarely, if ever made.

The fact of dispersal of larvae of *D. saccharalis* has been proved in Barbados, and the extent of dispersal can be indicated.

Proof of dispersal, (apart from catching newly hatched larvae on tanglefoot sheets) is supplied by four experiments carried out in 1935, 1936 and 1937 in plots of one sugar cane variety, B.726.

The dispersion of larvae of *D. saccharalis* is definitely shown by these experiments, and there can be no question that larval dispersion is of sufficient magnitude to vitiate any normally arranged plot experiments, so far as *D. saccharalis* is concerned. It may also account for much discrepancy of opinion and apparently negative results in assessing various control measures.

The writer has frequently pointed out the difficulty of controlling a pest such as *D. saccharalis*, which is not only well adapted to its host plant, but of which the host plant is in continuous growth, each crop taking from fifteen to eighteen months from planting to reaping.

Steady investigations into the problem do not tend to lessen the difficulty, but, by showing the complexity of the problem, also show the difficulty of obtaining any speedy or final results.

In Barbados, infestation by *D. saccharalis* is now about half of what it was in 1928 and 1929; it has been, in some years, less than half (3).

The principal difficulties of obtaining substantial reductions below the present average level are:—

(1) Fluctuating climatic conditions, which are known to affect both mortality rate of *Diatraea*, and effectiveness of the egg parasite *Trichogramma*.

(2) Changes in varieties of cane planted, and in acreages under such varieties.

(3) Larval dispersion whereby infested areas of cane raise infestation in less infested areas. There is reason to consider that larval survival is higher when pest population is lower; larval dispersion, therefore, becomes of increasing importance as reduction in pest population progresses.

Each of the above factors has been investigated in Barbados and each one is capable of varying the final average infestation by the yearly method now organised and standardised for Barbados.

Fluctuations in average annual infestation are therefore expected, but they now occur at a lower level of infestation, and are of lesser amplitude than would occur if there was no control.

The effects of climate on annual average infestation have been dealt with in (1) and the effects of changes in cane varieties have been dealt with in (2) and (3).

In all investigations published, it has been made clear that results are based on the cultivation conditions, and on the topographical climatic conditions which occur in Barbados, but which, quite possibly, occur no where else. It has also been stated that the extent of the subjects investigated make the statements so far published preliminary ones only : but for the ground they cover, they are based on adequate plot data and field experience.

Larval Distribution or Dispersal :

The investigations on this subject with respect to *D. saccharalis* and sugar cane, for conditions in Barbados are as follows.

Young, newly hatched larvae have been proved to be carried by wind or air currents by means of tanglefoot sheet exposures.

Newly hatched larvae have also been watched in the field from emergence from the egg mass to dispersal, and the mode of dispersal to the 'launching' of larvae from the leaf on which they hatched, has been observed.

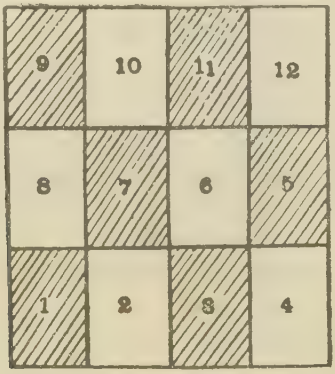
Field observations made over a number of years showed that stools of young cane could be found infested with *Diatraca,* though no egg masses, hatched or unhatched, could be found by a thorough search of such stools: also some fields or areas of cane would have an infestation out of all proportion to the egg masses which could be found deposited therein.

The following experiments were therefore arranged and carried out:—

Experiment I. Carried out in 1935 on cane planted in November, 1934, and due to mature in 1936.

Twelve plots each of 40 cane holes of B.726 were planted in a solid block as shown in diagram I. Each plot was searched for *Diatraca* egg masses three times a week. In the shaded plots, 1, 3, 5, 7, 9 and 11, the egg masses were

marked by coloured paint spots on the cane blades, and recorded as in previous experiments published. In the unshaded plots, the egg masses were counted, recorded *and removed*. As egg masses were removed three times each week there was very little possibility of any eggs hatching into larvae, for egg masses missed at one search would doubtless be found at the next search, and would still not have had time to hatch out. Plots 2, 4, 6, 8, 10 and 12 can, therefore, be considered as 'sterilised,' or as having 95 per cent. of all eggs deposited removal. Of the approximate 5 per cent. missed, some would be parasitised or destroyed by predators, so that the percentage hatching to larvae would be small, and the percentage survival still smaller.



DIAIGRAM 1

Each month a normal and a 'sterilised' plot were reaped and examined blade by blade and shoot by shoot for external evidence of larval damage to leaves and shoots, and for the presence of living *Diatraea* larvae and pupae and of empty pupal cases in the shoots. Records were kept at each examination of hatched, uncounted eggs in each plot. In only one case, namely a 'sterilised' plot, was there any appreciable escape in the form of *hatched* undiscovered eggs: this was at the end of the fourth month of the experiment, and when reaped, a total of 66 hatched eggs was found in plot 6. This represents the accumulated total for four months of search, is the worst record obtained and represents a small percentage of the total eggs deposited in the plot in question for those four months.

Taking this extreme case, however, and assuming a natural mortality of 75 per cent. and a survival of 25 per cent. of these larvae (which is a generous estimate) and that all the larvae remained in the plot, not more than 17 larvae could have survived or reached maturity in the plot during four months.

Nevertheless, when reaped, the plot contained 32 living larvae and five living pupae and seven empty pupal cases: that is thirty-seven living *Diatraea* and seven empty pupal cases, a total of forty-four *Diatraea*, and, in addition, there were 100 traces of larval feeding.

This will be seen from tabulated records below to be the statement for plot 6.

The corresponding statement for plot 5, which was a normal plot, was 30 unrecorded *hatched* eggs, and 52 living larvae and pupae. 15 empty pupal cases, and 143 traces of larval feeding. In that plot, however, there were the normal number of hatched, recorded eggs per month, in addition to the 30 unrecorded ones which had escaped the weekly searches.

As stated, plot 6 is picked out from the records given later as being the least satisfactory, from the point of view of sterilisation, a generous average of larval survival is allowed for that time of year, and no larvae are assumed to have dispersed from the plot: yet the plot has sufficient *Diatraea* actually present, apart from feeding traces, (which include dead hearts without larvae or pupae) to show a definite dispersal of larvae into the plot, from adjoining plots or other sources.

The records for all twelve plots are as follows:—

Normal Plots.

Plot 1. Reaped and examined 4.2.35.
One living larva.
No pupae.
28 traces of larval feeding.
Total evidence of *Diatraea* 29.
Total egg masses for month 52.
* Uncounted egg masses 9. (due to plot being reaped some days after last examination for egg masses) = 17.3 per cent.

Diatraea Sterile Plots.

Plot 2. Reaped and examined 4.2.35.
No living larvae.
No pupae.
22 traces of larval feeding.
Total evidence of *Diatraea* 22.
Total egg masses for month 44.
Uncounted egg masses 2 = 4.5 per cent.

Plot 3. Reaped and examined 1.3.35.
47 living larvae
2 living pupae } 49
87 traces of larval feeding.
Total evidence of *Diatraea* 136.
Total egg masses for 2 months 89.
Uncounted egg masses 5 = 5.6 per cent.

Plot 4. Reaped and examined 1.3.35.
12 living larvae
1 living pupa } 13
34 traces of larval feeding.
Total evidence of *Diatraea* 47.
Total egg masses for 2 months 61
Uncounted egg masses 7 = 11.4 per cent.

* *Note*: Uncounted egg masses have not all hatched to larvae: some are newly laid since last count, some parasitised and some destroyed by predators. The percentage of uncounted egg masses given for all plots below includes unhatched eggs and eggs destroyed by predators and parasites as well as *hatched* eggs.

Plot 5. Reaped and examined 2.4.35.
44 living larvae
8 living pupae } 67
15 empty pupae
143 traces of larval damage.
Total evidence of *Diatraea* 210.
Total egg masses for 3 months 145.
Uncounted egg masses 13 = 9.0 per cent.

Plot 6. Reaped and examined 2.4.35.
32 living larvae
5 living pupae } 44
7 empty pupae
100 traces of larval damage.
Total evidence of *Diatraea* 144.
Total egg masses for 3 months 109.
Uncounted egg masses 16 = 14.7 per cent.

Plot 7. Reaped and examined 1.5.35.
25 living larvae
11 living pupae } 56
20 empty pupae
185 traces of larval damage.
Total evidence of *Diatraea* 241.
Total egg masses for 4 months 140.
Uncounted egg masses 11 = 7.9 per cent.

Plot 8. Reaped and examined 1.5.35.
47 living larvae
7 living pupae } 73
19 empty pupae
164 traces of larval damage.
Total evidence of *Diatraea* 237.
Total egg masses for 4 months 176.
Uncounted egg masses 10 = 5.62 per cent.

Plot 9. Reaped and examined 4.6.35.
56 living larvae
3 living pupae } 87
28 empty pupae
241 traces of larval damage.
Total evidence of *Diatraea* 328.
Total egg masses for 5 months 198.
Uncounted egg masses 10 = 5.0 per cent.

Plot 10. Reaped and examined 4.6.35.
46 living larvae
2 living pupae } 62
14 empty pupae
171 traces of larval damage.
Total evidence of *Diatraea* 233.
Total egg masses for 5 months 139.
Uncounted egg masses 15 = 10.8 per cent.

Plot 11. Reaped and examined 1.7.35.
112 living larvae
4 living pupae } 140
24 empty pupae
188 traces of larval damage.
Total evidence of *Diatraea* 328.
Total egg masses for 6 months 276.
Uncounted egg masses 9 = 3.2 per cent.

Plot 12. Reaped and examined 2.7.35.
99 living larvae
10 living pupae } 129
20 empty pupae
265 traces of larval damage.
Total evidence of *Diatraea* 394.
Total egg masses for 6 months 252.
Uncounted egg masses 15 = 6.0 per cent.

There is no significant difference between the means of the two treatments.

These records show clearly that the number of eggs which escape the tri-weekly search and sterilisation of plots, and which hatch and of which larvae survive to be effective, cannot account for the amount of *Diatraea* larval damage found, and still less for the number of living *Diatraea* found at each reaping in the sterilised plots. There must, therefore, be a definite larval migration or dispersal which causes sterilised plots to be a most as heavily infested as plots in which eggs are allowed to develop and hatch normally.

This conclusion is confirmed by three other independent experiments described below. In one case, plots were not reaped monthly, but were allowed to complete nearly twelve months from planting to reaping, and then reaped at one time, and infestation determined by external counts of bored joints in nearly full grown canes.

In another case, small isolated groups of five cane stools were used as plots. The result was always the same, namely, tri-weekly removal of *Diatraea* eggs, with a very small percentage of hatched undiscovered eggs, still resulted in such sterilised plots having a considerable infestation, often nearly equalling that of the plots in which eggs were not removed, but were allowed to hatch normally.

Experiment II. Carried out in 1936 on cane planted November, 1935, and reaped November, 1936.

Twelve plots, each of 40 cane holes of B.726 were planted as shown in diagram II. Egg counts were made as in the previous experiments, namely, three times a week. In the shaded plots 1, 3, 5, etc., egg masses were marked so that they could not be counted again, and left undisturbed: in the unshaded plots, 2, 4, 6, etc., egg masses were removed and destroyed after counting. Egg counts started at the end of the first week in January, 1936, and continued until the end of October, 1936. The canes were reaped block by block early in November, and the extent of *Diatraea* larval damage determined in each block by external counts of bored joints.

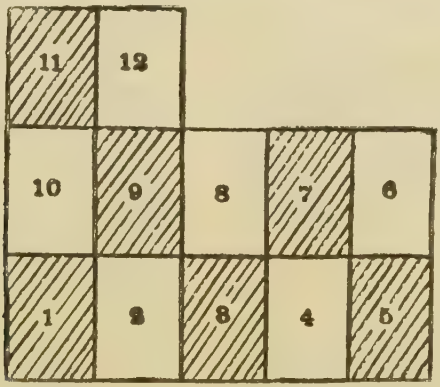


DIAGRAM II.

The results were as follows:—

Normal Plots.		Diatraea Sterilised Plots.	
Plot 1	16.50 per cent	Plot 2	13.74 per cent
„ 3	13.56 „ „	„ 4	13.33 „ „
„ 5	12.90 „ „	„ 6	8.07 „ „
„ 7	9.66 „ „	„ 8	12.47 „ „
„ 9	10.09 „ „	„ 10	9.35 „ „
„ 11	9.28 „ „	„ 12	8.68 „ „

The mean of the normal plots is 12.0 per cent. joints bored, and the mean of the sterilised plots is 10.94 per cent. joints bored.

There is no significant difference between the means of the two treatments.

Once again it is obvious that more larvae have reached and survived in the sterilised plots than could possibly be accounted for by larval survival from eggs missed and not destroyed, and which succeeded in hatching in the sterilised plots.

There is, therefore, a definite dispersal or migration.

It is also worth noting that the heaviest infestations occur in plots 1, 2, 3, 4 and 5 (in diagram II) which were immediately adjacent to and to leeward of a cane field, thus indicating a dispersal of larvae from this field.

Experiment III. Carried out in 1936 on cane planted in November, 1935. In this experiment, an area of slightly over one acre was marked out into nine squares, each approximately 70 feet by 70 feet.

Nine plots, each of five stools only, were planted: one in the corner of each square as shown in Diagram III.

The ground in between each plot of five cane stools was devoid of canes, as was a considerable area around the complete experimental area of one acre.

Each plot, or clump, of five stools was thus at least 60 feet from any adjacent plot or clump, and at least 250 feet from the nearest cane field.

The experiment was primarily to discover whether *Diatraea* larvae, as well as moths, could arrive in and infest small isolated plots of five stools each, and to what extent small isolated sterilised plots would compare in infestation with similar, but unsterilised, plots.

As a secondary consideration three of the nine plots had *T. minutum* placed in them at intervals, though both experience and common sense made it a certainty that the parasites would not stay in small exposed clumps of cane to an extent which would raise the parasite density permanently above similar untreated plots or clumps.

The lay out of the experiment was as in Diagram III.

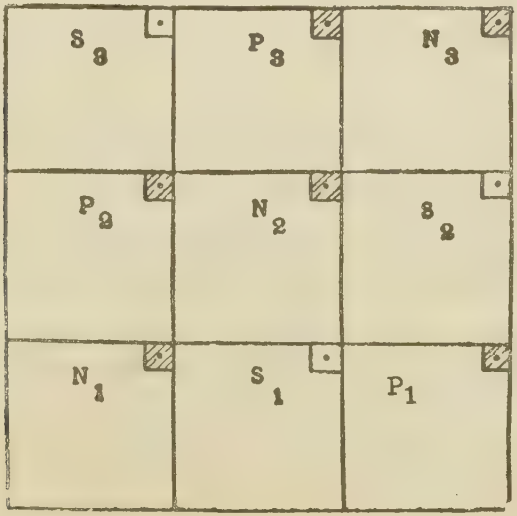


DIAGRAM III.

N. represents normal plots.
P. represents parasitised plots.
S. represents sterilised plots.

As with other experiments of this nature, egg masses in normal and parasitised plots were marked, recorded and left undisturbed and in sterilised plots egg masses were recorded and removed.

In contrast to other experiments, however, egg deposition in N and P plots was artificially equalised after each count by adding or removing eggs in numbers sufficient to make the total for each plot the same. Three times weekly, therefore, the numbers of eggs in N and P plots were equalised, though it was not possible to ensure that the eggs added to or removed from each plot were of the same age, or that they had not been recently parasitised, nor that they would be free subsequently from predator attacks.

It was, however, an attempt to obtain equality of egg deposition in two treatments of three plots each, and complete removal of eggs before hatching in the third treatment of three plots.

The results show (as with experiments recorded above) that fairly complete sterilisation of plots did not prevent moths from laying eggs in those plots, though few, if any, could have bred in such plots; and that, despite removal of eggs as laid, there was still a considerable infestation and damage by *Diatraea* larvae.

In the case of the plots with attempted equalisation of egg deposition, the effect of adding parasites appears to be to increase final infestation, though the figures have no mathematical significant difference, and the numerical additions of parasites were small (being made proportional to the size of the plots) and could not, as stated before, be expected to cause any permanent increase in parasite population effectiveness in such small, isolated and exposed plots.

The results are summarised below:—

Plots N_1 N_2 & N_3			Plots P_1 P_2 & P_3		
Total living larvae and pupae	79	118	Total living larvae and pupae	136	174
Total empty pupae	39		Total empty pupae	38	
Total cane joints 3,645 of which 699 bored.			Total cane joints 3,421 of which 719 bored		
Percentage bored in N Plots = 19.17			Percentage bored in P. Plots = 21.01		
(N_1—15.35 per cent.)			(P_1—19.84 per cent.)		
(N_2—20.05 per cent.)			(P_2—26.45 per cent.)		
(N_3—21.23 per cent.)			(P_3—17.34 per cent.)		

S_1 S_2 & S_3

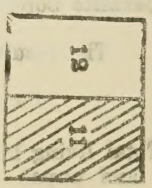
Total living larvae and pupae	**52**	**66**
**Total empty pupae .. .. ..

This experiment indicates most decisively the spread or dispersal of *Diatraea* larvae by air currents, wind, etc., inasmuch as the plots were exceedingly small (5 cane stools) well isolated, and any dispersal by means of interlocking foliage, obviated.

Experiment IV. Carried out in 1937 on cane planted in November, 1936, and reaped, two plots at a time from the end of January, 1937, to end of June, 1937. This experiment is on similar lines to that carried out in 1935 on cane planted in November, 1934.

It differs, however, in that it was not possible to obtain a solid block of cane, and two plots had to be separated from the others: the situation, also, was not of the best for cane growing and the growth of some plots was poor.

The lay out of the experiment was as in Diagram IV:—



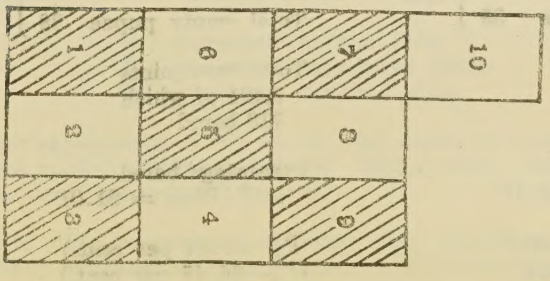


DIAGRAM IV

The procedure for the experiment was the same as in Experiment I.

The number of egg masses missed during the tri-weekly counts, but found when plots were reaped and examined, blade by blade, in the laboratory was as follows:

Plot 1—None.
Plot 2—None
Plot 3— 3
Plot 4— 1
Plot 5— 3
Plot 6—None
Plot 7— 15
Plot 8— 13
Plot 9— 9
Plot 10— 3
Plot 11— 8
Plot 12— 5

In the twelve plots, therefore, a total of sixty-five egg masses were missed during the period of the experiment—namely six months. The total of egg

masses found and recorded for this period was 1,221: the percentage of uncounted egg masses is therefore low, namely 5.3 per cent. of total.

Out of the 65 masses missed, 26 were unhatched masses which had been deposited between egg counts and the reaping of respective plots. Only 39 masses therefore could have produced larvae for the entire twelve plots, and, of these masses, some were parasitised or destroyed by predators.

The number of effective surviving larvae in the six sterilised plots would therefore be very small and less than in Experiment I in which 122 egg masses were recorded as missed out of a total for six months of 1,681 masses.

The plot results are as follows:—

Normal Plots.		*Diatraea Sterilised Plots.*	
Plot 1.		*Plot 2.*	
Diatraea recovered	0	*Diatraea* recovered	0
Records of larval damage ..	37	Records of larval damage ..	41
Total evidence of *Diatraea* ..	37	Total evidence of *Diatraea* ..	41
Plot 3.		*Plot 4.*	
Diatraea recovered	3	*Diatraea* recovered	3
Records of larval damage ..	57	Records of larval damage ..	57
Total evidence of *Diatraea* ..	60	Total evidence of *Diatraea* ..	60
Plot 5.		*Plot 6.*	
Diatraea recovered	18	*Diatraea* recovered	20
Records of larval damage ..	96	Records of larval damage ..	102
Total evidence of *Diatraea* ..	114	Total evidence of *Diatraea* ..	122
Plot 7.		*Plot 8.*	
Diatraea recovered	105	*Diatraea* recovered	37
Records of larval damage ..	258	Records of larval damage ..	139
Total evidence of *Diatraea* ..	363	Total evidence of *Diatraea* ..	176
Plot 9.		*Plot 10.*	
Diatraea recovered	41	*Diatraea* recovered	9
Records of larval damage ..	158	Records of larval damage ..	73
Total evidence of *Diatraea* ..	199	Total evidence of *Diatraea* ..	82
Plot 11.		*Plot 12.*	
Diatraea recovered	49	*Diatraea* recovered	24
Records of larval damage ..	522	Records of larval damage ..	229
Total evidence of *Diatraea* ..	571	Total evidence of *Diatraea* ..	253

There is no significant difference between the means of treatments.

The six normal plots produced a total of 216 *Diatraea* recovered, and 1,112 records of larval damage for the period of the experiment. The six sterilised plots produced a total of 93 *Diatraea* recovered and 641 records of larval damage; this, as in other experiments recorded above, may have a biological though not a mathematical significance.

In this experiment, sterilisation of six plots appears to have had a greater effect in reducing the amount of recoverable *Diatraea* and of *Diatraea* damage in such plots, compared with the results of Experiment I. This may, in part, be due to the more effective sterilisation of the Plots, and in part to the different lay out of the experiment.

The outstanding fact, however, shown in this, as in all the preceding experiments, is that there is a definite and incontrovertible dispersal of *Diatraea* larvae from other sources into the sterilised plots, which, for the type and extent of the experiments undertaken, renders a high standard of *Diatraea* sterilisation of plots ineffective so far as statistical analysis goes.

There is also very little difference in the number of egg masses laid in sterilised compared with normal plots: and, as very few indeed of the moths laying the eggs can have originated in the sterilised plots, there is an evident dispersal of moths. The latter point is, however, more usually recognised and admitted than is the fact of larval dispersion which the foregoing experiments are held to prove.

With a definite and proved larval and moth dispersal, the futility of ordinary plot or block experiments to prove *Trichogramma* control on a statistical basis is obvious, particularly as *Trichogramma* accustomed to a cane field habitat, have also a considerable power of dispersal.

SUMMARY.

1. A series of plot experiments were carried out in 1935, 1936 and 1937, in which in specified plots, a high proportion of *Diatraea* eggs were destroyed before they could hatch. These plots are referred to as sterilised in respect of *Diatraea saccharalis*.

2. The lay out of each experiment is given, together with method and results. Three of the experiments differ in method and the fourth, though identical with the first in method, differed unavoidably in lay out.

3. In all cases, whatever the method or lay out, results showed a degree of infestation of the sterilised plots by *D. saccharalis* which can only be accounted for by larval dispersal from other sources. This effective larval dispersal is proved to be considerable, and to result in all statistical analyses of treatments giving non-significant results. The usual method of larval dispersal is shown to be by drift of newly hatched larvae on air currents.

4. The number of *Diatraea* eggs laid in sterilised plots was very little different from the number laid in normal plots, showing moth dispersal as well. Parasite dispersal is an equally recognised fact. It is held that effective larval dispersal is, in the case of *Diatraea saccharalis*, an additional factor which has not been accorded sufficient recognition.